much less. For example, at the 12-dB level, the data from tbe diversity pairs separated by seven and nine miles show about a factor of 50 improvement over tbe individual distributions. Tbe difference between the curves near the bottom of Fig. 1 should not be taken as very significant since the data in those portions of the curves are from only a few rains. The attenuation scale for Fig. 1 is based on $T = 273°$ wbich is a good fit to 1968 sun tracker data. During the 129 days used for this data sample, 15.26″ of rain fell at Crawford Hill.

Thus, spacings of from five to ten miles provide considerable diversity advantage on earth-space paths at 16 GHz. The experiment is continuing but the Parkway station has been moved from two miles to twelve miles southeast of Crawford Hill. This will make available diversity data for spacings of seven, twelve and nineteen miles.

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First Result from 15.3-GHz Earth-Space Propagation Study

By A. A. PENZIAS

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Consideration is being given to the use of frequencies well above 10 GHz for satellite communication. One of the problems encountered in tbe use of these high frequencies is the attenuation caused by precipitation. A considerable amount of pertinent data has been obtained in the 16- and 30-GHz sun tracker and 16-GHz radiometer programs underway at the Crawford Hill Laboratory.[1,2] From the data obtained from radiometer measurements, one may calculate the attenuation expected on an earth-space patb. Such attenuation calculations have been shown to be in good agreement with sun tracker measurements.[1] Tbe present experiment was designed to check further the validity of the radiometer results by a direct comparison of the data obtained from a 16-GHz radiometer witb the attenuation measured by transmission from a

satellite at a nearby frequency. This experiment was made possible by the inclusion by NASA of two 200 MW, 15.3-GHz transmitters aboard the Fifth Applications Technology Satellite (ATS-5).

The Fifth Applications Technology Satellite was launched into a synchronous orbit in early August 1969. It arrived at its station at lon 108° a month later. Owing to a partial malfunction during the second stage of the launching sequence, the satellite spins at a rate of about 60 rpm. As a result signals are received from the satellite for only 40 milliseconds out of each second, when the transmitting antenna momentarily points at the earth during each revolution. Although this reduces the average signal level by 14 dB, it is still possible to obtain a measuring range of approximately 20 dB with our receiving system.

The receiving antenna is the 20-foot horn-reflector at Crawford Hill. Although originally designed for the 2.39-GHz Echo project, it was found to be quite satisfactory at 15 GHz.

The experiment employs two separate receiving systems, the 15.3-GHz satellite receiver and a 16-GHz radiometer supplied by R. W. Wilson. They are mounted at the antenna throat to receive orthogonal polarizations, with their outputs recorded simultaneously on a two-pen chart recorder.

The satellite receiver uses a conventional 15.3-GHz waveguide balanced mixer receiver with an IF amplifier 100-kHz wide at 70 MHz. Since signal phase information is not required, no phase locking to the signal is used; the local oscillator is merely stabilized at 15,230 MHz. The output of the IF detector is connected through a capacitor to a peak detector. This peak detector is sensitive only when the transmitted signal is "on", hence more or less maintaining the signal to noise ratio expected without spinning. The discharge time of the circuit was designed to be $\sim$4 sec in order to reduce the noise fluctuation level by "averaging" over about four pulses.

Data were taken at our site for all rainstorms occurring during the time the satellite was transmitting in the three-month period following the initial ATS-5 transmitter turn-on on October 4, 1969. In only one of these storms (November 19 and 20, 1969) did the attenuation exceed 3 dB. Data taken during this storm is shown in Fig. 1. It is a plot of measured attenuation of the received satellite signal versus attenuation computed from the 16-GHz radiometer record at corresponding times. The size of the bars indicate the estimated measurement errors. The dotted line corresponds to an attenuation ratio of 1.1 between 16 GHz and 15.3 GHz. (The attenuation due to rain increases approximately with the square of the frequency in this wavelength region.) A good

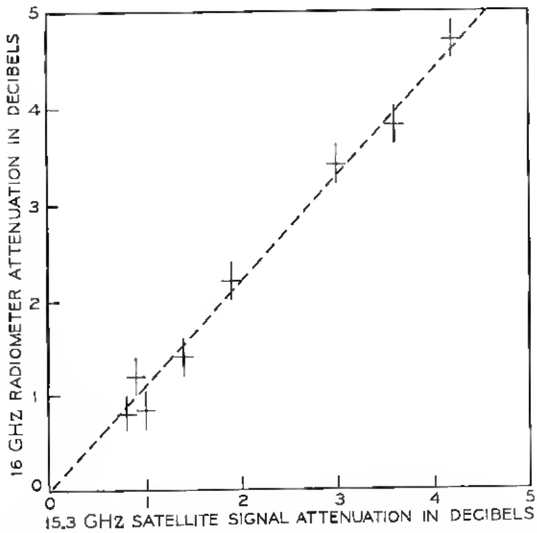

Fig. 1—Data recorded during storm on November 19 and 20, 1969.

correspondence between the radiometer and satellite data is evident in the figure.

The long-term stability of the signal transmitted from the satellite was not good enough to permit absolute attenuation measurements over the duration of the rainstorm (about seven hours). Instead, attenuation was measured incrementally for short periods of heavy rain, each some few minutes in duration, which appeared as distinct absorption features on the record. The attenuation points plotted in the figure are thus actually differences from "baselines" drawn between fiducial points of low rain attenuation adjacent to each feature. A corresponding subtraction was also made in each case for the radiometer record. In no case did this correction exceed 0.3 dB at 16 GHz.

In addition to the data from this storm, attenuation due to rain in excess of $\sim$1 dB was noted on the radiometer record on a number of other occasions. In each case a corresponding dip in the received satellite signal was also recorded. Within the accuracy of this latter record, typically $\pm$0.2 dB, definite correspondence of the records was obtained, indicating clearly that the radiometer data is a reliable measure of attenuation over the range of storm intensities measured so far. (Note added in proof: In the spring of 1970, a number of rainstorms were measured with results quite similar to those reported above. The most intense storm for which reliable data was obtained occurred during

the afternoon of April 24, 1970. The peak measured 15.3-GHz signal attenuation and the corresponding 16-GHz radiometer record were 9.8 dB and 10.6 dB respectively.)

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Intersymbol Interference and the P/AR Meter

By J. H. FENNICK

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P/AR stands for peak-to-average ratio. The instrumentation to measure this ratio has been assembled and obtains a single number evaluation to the dispersion in a transmission medium by measuring the peak and the full wave rectified average of a pulse stream.[1,2]

The P/AR meter has been under exploratory study and use for several years now. Many empirical studies have been made relating the P/AR rating to data transmission performance in the presence of gain and phase distortions. This study was undertaken to demonstrate the relationship between P/AR and intersymbol interference in pulse transmission caused by deviations from linear phase of passive networks.

Appropriately weighted peak and rms intersymbol interference has been calculated for 19 passive all-pass networks. The results were correlated with the P/AR ratings of the networks to determine the relationship between P/AR and intersymbol interference due to phase distortion. The values of P/AR ranged from 30.86 to 97.58. The results show that P/AR has a correlation coefficient of -0.94 with rms intersymbol interference and -0.98 with peak intersymbol interference.

E. D. Sunde demonstrated in 1954 that rms and peak intersymbol interference in pulse transmission could be calculated by the following procedure.[3] The departures from a linear phase characteristic may be represented by a Fourier series expansion of the form $f(w) =$